UNITED STATES OF AMERICA:
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SIGNAL SERVICE NOTES

No. IV.

THE USE OF THE SPECTROSCOPE

IN

METEOROLOGICAL OBSERVATIONS.

PREPARED UNDER THE DIRECTION OF
BRIG. & BVT. MAJ. GEN'L W. B. HAZEN,
CHIEF SIGNAL OFFICER OF THE ARMY,

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USE OF THE SPECTROSCOPE IN METEOROLOGICAL OBSERVATIONS.

About ten years ago it was suggested by Professor Piazzi Smyth, Astronomer Royal of Scotland, that the variable lines in the solar spectrum, due to the absorption of aqueous vapor, might be made available for the forecasting of rain. This conclusion he justified by numerous experiments, which he has continued to the present time, and which have been repeated by other observers with similar results.

The object of this paper is to give briefly the results of observations made regularly with a pocket spectroscope, and to explain their value for meteorological uses. The conclusions derived are in the main similar to those already published by various authors;* it is hoped that their presentation in this form may secure the attention of some who are at present unfamiliar with the subject.

The aqueous lines of the spectrum are found principally in the red, orange, and yellow portions, and their appearance varies with the amount of aqueous vapor held suspended in the atmosphere at different times. The most prominent group is situated on the red side of the conspicuous D line, immediately adjacent to it, and is known as the "Rain-band." On account of its prominence and its variability under different hygrometric conditions, it is especially adapted for observations the aim of which is to note its intensity at different times, and to infer therefrom the relative conditions of the atmosphere with respect to aqueous vapor.

The accompanying chart, No. i., is designed to represent the appearance, under two widely different conditions, of that portion of the spectrum in which the rain-band is situated. The spectroscope used in making the observations from which the chart is derived consisted of a grating with 17,296 lines to the inch, and a telescope of 18 inches solar focus, with an aperture of 1⅞ inches. The position of the lines was determined by means of a scale reflected into the field of view and is intended to be only approximately correct. The upper half of the chart was made near noon, the image of the sun being thrown upon the slit by a porte-lumiere; the lower was made just before sunset, with the sun shining directly upon the slit. The additional lines shown upon the latter, and the increased heaviness of some, are due mainly, as has been shown by Janssen and others, to the aqueous vapor of the atmosphere. These effects are made apparent near sunset because the sunlight at that time reaches the instrument through a much greater thickness of the atmosphere than it is obliged to penetrate when the sun is high in the heavens. These lines are also more conspicuous the greater the amount of aqueous vapor existent in the atmosphere.† More extended charts of the atmospheric lines of the spectrum have been published by Angstrom, (see "Shellen's Spectrum Analysis,") by Hennessey in "Philosophical Transactions" for 1875, and by Janssen in "Annales de Chemie et Physique" for 1871.

* See articles by Professor Piazzi Smyth in "Edinburgh Astronomical Observations," vol. xiv.; "Nature," vol. xii., pp. 231 and 252; vol. xiv., p. 9; vol. xvi, p. 389; vol. xxii, p. 194; "Journal of the Scottish Meteorological Society," vols. li. and lv.; "Knowledge," vol. ii., No. 48; "Madeira Meteorologic," which contains a comparison of results at Edinburgh, Lisbon, and Madeira. Also "A Plea for the Rain-band," by J. Rand Capron, Esq., in "Symons' Meteorological Magazine," Dec., 1881. In addition, there have appeared various articles in current periodicals.

† It should be noted that the chart does not represent the relative appearances of the rain-band in the same portion of the sky under different hygrometric conditions, but the relative appearances in two portions of the sky whose altitude differs greatly.

Viewed in a small pocket spectroscope, like the direct vision spectroscopes made by Browning or Hilger, this group of lines is reduced to a mere shading attached to the D line, varying in intensity with the altitude of that part of the sky examined; or, if the instrument is pointed always toward the same portion of the sky, varying with the hygrometric condition of the column of air through which light comes to the instrument. It is not necessary to point the instrument toward the sun, and, indeed, with a small spectroscope, it is better to obtain the spectrum from the sky itself. The observation consists in estimating the intensity of the shading under different conditions, and thus obtaining a rough idea of the hygrometric state of the air.

The plan adopted in making observations has been as follows :—

1. The spectroscope is directed to the sky near the horizon, and the intensity of the band estimated upon a scale of 5.

2. The spectroscope is then directed to the sky at an altitude of 45°, and a similar estimate is made.

3. The sum of the two readings is taken as the value for the observation, which is therefore upon a scale having 10 for its maximum. The observation at the altitude of 45° is quite as important as the one near the horizon. When the band decreases in intensity but little as the instrument is elevated from the horizon, it gives strong evidence of an undue amount of aqueous vapor in the upper atmospheric strata. It sometimes happens that the decrease is but slight, even to the zenith, in which case, except when this is caused by clouds, heavy rain is almost sure to follow.

Under ordinary hygrometric conditions at 7 a. m. in summer, I estimate 3 as the reading for the horizon pointing, and 2 as the reading for the 45° pointing. Thus 5 represents, upon my own mental scale, an average aqueous condition of the atmosphere at that hour, and readings giving greater values than 5 indicate an amount of aqueous vapor in the atmosphere above the average.

In order to illustrate the results obtained, I have selected the observations made daily at 7 a. m., at Washington, D. C., from July 1 to August 15, 1882. These are given in the form of a chart, No. ii, on page 18, which also contains, for the purposes of comparison, diagrams of the absolute and relative humidity obtained from the readings of a wet and dry-bulb thermometer, and of the rainfall. The observations were made with a Browning direct-vision spectroscope of five prisms, upon the plan outlined above. They have been entered upon the chart opposite their respective dates and connected by straight lines. It should be noted that the lines connecting the several observations of absolute and relative humidity, as well as of rain-band, do not represent the course of the humidity during the twenty-four hours of the day, but simply connect observations made at intervals of a day. The diagram illustrating the rainfall represents the rain recorded during the twenty-four hours between successive observations.

It will be seen from the chart that the following conclusions may be derived; they are justified by all the observations made, as well as by those of other observers that have been published :—

1. There is a general agreement between the rain-band curve and the curves of absolute and relative humidity. Such an agreement is to be expected if the rain-band indications have any hygrometric value.

2. Individual discordancies are often found between the respective curves. This is also to be expected, for if discrepancies did not exist there would be no advantage in the rain-band observations over those of the ordinary psychrometer. It is therefore necessary, in asserting that the former observations have an advantage over the latter, to point to cases in which this superiority is manifest. Two examples are indicated on the chart :—

(1) July 29: Rain-band, 6; absolute humidity, 8.1; relative humidity, 97. On this morning, rain had just ceased and the sky soon after cleared. The upper strata of

the atmosphere probably contained but little aqueous vapor, while the lower strata were nearly saturated.

(2) August 6: Rain-band, 4; absolute humidity, 8.8; relative humidity, 98. The absence of rain on this day indicates that the rain-band observation conveys a better idea of the hygrometric condition of the atmosphere, as a whole, than is given by the psychrometer.

A still better illustration is furnished by the following table, which gives the observations made through fog on the mornings of October 4–8, 1882. The relative humidity observed at 3 p. m., after the fog had cleared away, is added for comparison:

	Band.	*Rel. Hum.*	*Rel. Hum.* 3 *p. m.*
October 4, 1882, 7 a. m.	4	95	58
" 5 " "	4	95	56
" 6 " "	3	100	47
" 7 " "	4	90	55
" 8 " "	4	100	59

It will be noted that the relative humidity at 3 p. m. averages 41 per cent. below that at 7 a. m. The usual decrease in October at Washington between 7 a. m. and 3 p. m. is 28 per cent. The superiority of the rain-band observations in indicating the true humidity of the air is in this case evident.

3. The observations are not always satisfactory. If we compare them with the rainfall record it will be seen at once that the rain-band is not an infallible indicator of rain; thus the large rainfalls recorded on July 12th and 28th were not indicated by any of the hygrometric observations, with either the spectroscope or the psychrometer. The observation is also partially or wholly a failure, as far as forecasting rain is concerned, when the sky is covered with clouds; thus on August 12th, it was raining at the time of observation, and in consequence, both the rain-band and the humidity were high, but the sky cleared soon after the observation. There are also cases, as on July 8th, 9th and 10th, when an observation of the rain-band giving a value above the average, was not a precursor of rain.

The fact that it indicates the combined hygrometric condition of a large part of the atmosphere, and not of the lower portion alone in which the instrument is situated, constitutes the superiority of the rain-band observation. This great advantage is, however, in some measure offset by the indefinite nature of the observation itself. The rain-band is, under the most favoring conditions, quite small and faint, and therefore requires skill and experience in the observer to record its variations. In addition, there is no fixed scale by the aid of which the observer can estimate variations. Each observer is compelled to adopt for himself a mental scale which is liable to change somewhat from day to day. The scale will be different for different observers and different instruments, and, in consequence, there is difficulty in comparing the results obtained. It is probable that improvements in the spectroscopes employed will remove these disadvantages, in the event of which the superiority of the instrument for hygrometric observations will be much increased.

The exact significance of spectroscopic observations of the rain-band may be readily inferred from what has been written above. It may be summarized as follows:

The rain-band spectroscope is a form of hygrometer which gives a rough estimate of the aqueous condition of a large portion of the atmosphere. Its superiority over the psychrometer or other hygrometers is due to its power of taking account of the aqueous vapor present in the upper as well as in the lower atmospheric strata; but this advantage is partially neutralized by the uncertainties attaching to the method of observation.

The relation of observations of the rain-band to rainfall is found in the fact that the former indicates simply the *aqueous condition* of the atmosphere, but not necessarily

that this vapor will be precipitated. Precipitation depends upon several meteorological conditions, of which the quantity of aqueous vapor held suspended in the atmosphere is but one; it is this condition only which the spectroscope reveals, but a knowledge of the others is requisite for the forecasting of rain.

The rain-band observations are especially interesting to meteorologists because they are an attempt to obtain by instrumental means a knowledge of the conditions prevailing in the higher regions of the atmosphere. These regions are the seat of atmospheric disturbances whose presence is known chiefly by the variations of barometric pressure, and by the forms and movements of the clouds. An additional meteorological instrument is, therefore, supplied by the spectroscope, by which results of considerable value have already been obtained, and from which greater results may be hoped in the future. The observations have more value in summer than in winter, and are useful in anticipating local rains.

It should be borne in mind, however, that for the amateur, the observation with a small pocket spectroscope is not very easy, because of the minuteness of the band under the best circumstances. To this cause is probably to be attributed, the failure of some to obtain any results, and their consequent belief that nothing can be done with the instrument. Satisfactory observations can be secured only by a skillful observer. Even then, it must be admitted, that the observation is crude and superficial, and ought not to be regarded as the best that science can offer. With larger spectroscopes properly mounted, still more satisfactory observations have already been made than are possible with the pocket instrument, while the subject of atmospheric absorption, of which the rain-band is a small part, is today receiving considerable attention at the hands of spectroscopists.

SUGGESTIONS TO OBSERVERS.

The following suggestions are offered for the benefit of any who may attempt observations with the pocket spectroscope:

Special attention should be given to the focus and the adjustment of the slit. The ordinary solar lines that are visible must be made as black and distinct as possible. To secure this the colors of the spectrum must not be too bright. It is well to adjust the slit and the focus by successive trials until the solar lines are most clearly defined. The lines in the green (E and b) will aid in the adjustment, but the distinctness of the D line itself should be the final aim.

It is a good plan to shade the eye with the hand so that no light shall be received except that which comes through the instrument. A cloth thrown over the head, as is done by photographers, is a still better precaution.

If observations near the horizon and also at 45° altitude are to be made, the spectroscope should be elevated to an altitude of about 20° in adjusting the focus and slit. Then the readings of both points can be made without alteration of any adjustments. The spectral lines will not appear as distinct for higher altitudes as for lower.

The formation of the mental scale of comparison should receive careful attention. The maximum intensity must be determined by experiment. It may often be obtained from the western sky at sunset, or still better by examining the sky just before a heavy rain storm, or while rain is falling. Some observers adopt the scale 0 to 10, but it will be found that the scale 0 to 5 presents as many gradations as can well be estimated.

It is always preferable to make the observation in portions of the sky free from clouds. Aside from this precaution, the north or northwest sky may be selected.

If but one observation is possible daily, an hour between 7 and 10 a. m. should be chosen, but observations taken at several different times, as at 8 a. m. 12 m., and 4 p. m., are to be recommended. By all means, other meteorological observations

should be made at the same time. The most important of these are wet and dry-bulb thermometers, barometer, direction and velocity of wind, character and amount of clouds. Radiation instruments, if at hand, should also be read.

It is a good plan to attempt local predictions of "Rain" or "No Rain" in connection with the observations. These predictions should be based on all the weather conditions at hand rather than on those of the rain-band alone.*

In order to aid the beginner in acquiring information as to the appearance of the rain-band, chart No. iii. is given. This is reproduced from "Symons's Meteorological Magazine," for December, 1881, and illustrates the article by J. Rand Capron, F. R. A. S., entitled "A Plea for the Rain-band." The drawing was made with a more powerful instrument than the pocket spectroscope, but it gives a good representation of what may be expected in the latter. The rain-band is the shading at the left of the D line; the colors of the spectrum ranging from red on the left, to blue on the right. In a small spectroscope, the D line will appear single, and the maximum shading will hardly exceed that in (4). The following description of the drawing is taken from the article referred to.

By the term "low sun-band," is meant the band at the right of the D line. This is a variable band, but it is thought that it is not due to aqueous vapor. It is regularly observed by Professor Piazzi Smyth, together with the rain-band—

"To enable the observer to judge of the general appearance and intensity of the larger rain-band near D, I have given some drawings of spectra as seen in a spectroscope of small dispersion, of which the following is a discription:

"(1) Spectrum as seen upon a pure high sky, showing principal solar and telluric lines in their proper positions, and with their designations, but not showing the finer lines between, nor any bands.

"(2) Spectrum observed January 17, 1881, 8 a. m. Morning dull; red sunrise; low sun-bands and lines (note especially band to right of D) strong. *No* rain-band.

"(3) Spectrum observed August 24, 1881, 8 a. m., showing moderate low sun-bands and lines, and a *faint* rain-band, with rain lines showing through.

"(4) Spectrum seen November 16, 1880, 1 p. m. Rain and wind, but clearing in some parts of the sky. Low sun-bands and lines weak. Rain-band *moderate.*

"(5) Spectrum seen December 9, 1880, 8 a. m. Sun shining through watery clouds. Low sun-lines strong. Rain-band *strong.*

"(6) Spectrum seen July 6, 1881. Rain-band everywhere, and *exceptionally* strong, stretching nearly half way between C and D. Whole spectrum darkened and obscured.

"The above-described drawings do not give, except in a rough way, the details of the lines and bands other than the rain-band, which is situate to the left of the double line D, and has its place marked by an R."

Of the works upon this subject none have been written, as far as I have learned, by other than English authors. The most important of these are found in the "Edinburgh Astronomical Observations," vol. xiv., by Professor Piazzi Smyth, and in "Symons's Meteorological Magazine" for December, 1881, by J. Rand Capron, F. R. A. S. The latter is issued as a separate pamphlet by John Browning, of London, and accompanies his "Rain-band Spectroscope." Works on spectrum analysis, by Schellen, Roscoe, and Lockyer may also be consulted with advantage upon the subject of atmospheric absorption.

*Out of 49 predictions made at 7 a. m. of "Rain," or "No Rain," for the succeeding twenty-four hours, based upon the rain-band alone, 34, or 69 per cent. were verified. Out of 49 similar predictions, taking account of all known weather conditions, 41 or 84 per cent. were verified.

Chart No. I.

Lines in the Spectrum comprising the Rain Band.

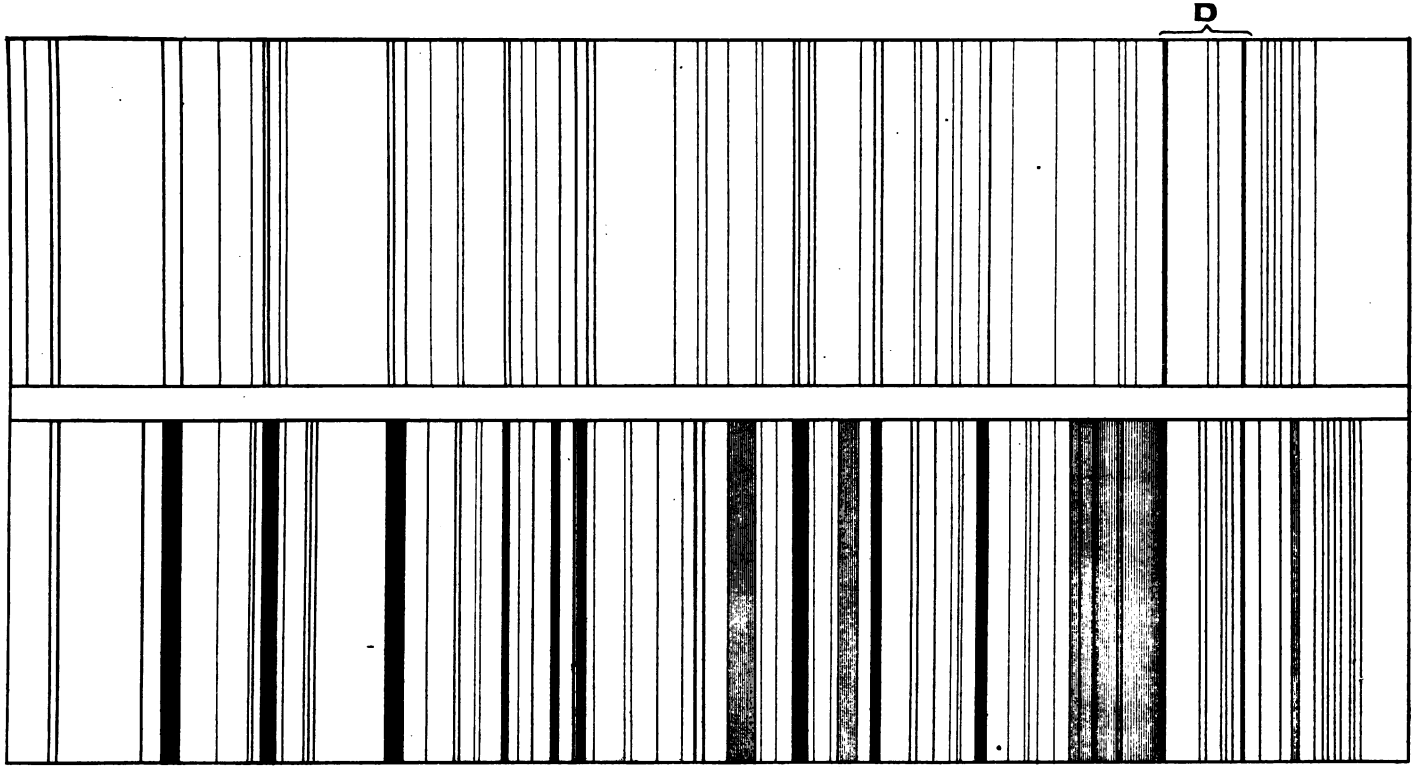

Chart No 2.

Rain Band Observations from July 1, to Aug. 15, 1882, made at Washington, D.C.

THE RAIN BAND IN SPECTROSCOPE
OF MODERATE DISPERSION.